Performance-Based Earned Value

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Performance-Based Earned Value® (PBEV℠) is an enhancement to the Earned Value Management Systems (EVMS) standard [1]*). PBEV overcomes the standard's shortcomings with regard to measuring technical performance and quality because it is based on standards and models for systems engineering, software engineering, and project management. The distinguishing feature of PBEV is its focus on the customer requirements. PBEV provides principles and guidance for cost-effective processes that specify the most effective measures of cost, schedule, and product quality performance.*

Program managers (PMs) expect accurate reporting of integrated cost, schedule, and technical performance when the supplier's Earned Value Management Systems (EVMS) complies with the EVMS guidelines in the American National Standards Institute (ANSI)/ Electronic Industries Alliance (EIA) Standard-748-A-1998. However, EVM data will be reliable and accurate only if the following occurs:

- The indicated quality of the evolving product is measured.
- The right base measures of technical performance are selected.
- Progress is objectively assessed.

Using EVM also incurs significant costs. However, if you are measuring the wrong things or not measuring the right way, than EVM may be more costly to administer and may provide less management value [2].

EVMS Shortcomings

The EVMS standard has significant shortcomings with regard to standards and models for systems engineering (SE), software engineering, and project management. Consequently, there is no assurance the reported earned value (EV) is based on product metrics and on the evolving product quality as defined by the standards and models.

First, the EVMS standard states that EV is a measurement of the quantity of work accomplished and that the quality and technical content of work performed are controlled by other processes. A PM should ensure that EV is also a measurement of the product quality and technical maturity of the evolving work products instead of just the quantity of work accomplished. However, a Naval Air Systems Command (NAVAIR) organization that used EVM and the Team Software Process℠ to accelerate software process improvement concluded that EVM did not address product quality and was not beneficial at the higher levels of the Capability Maturity Model® (CMM®) for Software [3].

Second, the EVMS principles address only the project work scope. EVMS ignores the product scope and product requirements.

Third, EVM is perceived to be a risk management tool. However, EVMS was not designed to manage risk and does not even mention the subject.

The following guidance will enable a PM to use Performance-Based Earned Value® (PBEV℠) to overcome the limitations of EVMS and provide a framework for utilizing PBEV as a key component of project planning, measurement, and control. The guidance is based on actual project experience and has contributed to the success of software-intensive programs, including the B-2 stealth bomber.

Table 1: *Department of Defense System Engineering Policy and Guides*

DoD SE Policy and Guides	Policy	DAG	SEP Guide
Develop systems engineering plan.	P	4.2.3.2	1.0
Event-driven timing of technical reviews.	P	4.5.1	3.4.4
Success criteria of technical reviews.	P	4.5.1	3.4.4
Assess technical maturity in technical reviews.		4.5.1	3.4.4
Integrate SEP with integrated master plan.		4.5.1	3.4.5
Integrate SEP with integrated master schedule.		4.5.1	3.4.5
Integrate SEP with technical performance measures (TPM).		4.5.1	3.4.4
Integrate SEP with earned value management.		4.5.1	3.4.5
Use TPMs to compare actual versus planned technical development and design maturity.		4.5.5	3.4.4
Use TPMs to report degree to which system requirements are met in terms of performance, cost, and schedule.		4.5.5	3.4.4
Use standards and models to apply systems engineering.		4.2.2, 4.2.2.1	
Institute requirements management and traceability.		4.2.3.4	3.4.4
Use EVM.		11.3.1	

Department of Defense Policy

Compliance with SE standards will support the Department of Defense (DoD) acquisition policy that programs will implement SE plans (policy) [4]. The DoD also published the Defense Acquisition Guidebook (DAG) and the Systems Engineering Plan (SEP) Preparation Guide (SEP Guide) to provide discretionary best business practices to complement the policy. The SEP Guide cites engineering standards[1] that are sources of PBEV [5]. Table 1 shows pertinent policy components and implementing guidelines.

Product Metrics and Quality

The Institute of Electrical and Electronics Engineers (IEEE) 1220 and the EIA 632 have similar guidance regarding product metrics and quality. Product metrics allow assessment of the product's ability to satisfy requirements and to evaluate the evolving product quality against planned or expected values. Establishing a time-phased product quality requirements baseline against which progress can be measured normally precedes the schedule and budget. An exception for the system definition stage of the systems development life cycle, before the real product quality requirements are known, is discussed later. Of equal importance are a disciplined requirements traceability process and a requirements traceability database [6].

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Success Criteria

The standards discuss the importance of holding technical reviews at various stages of development to assure that all success criteria have been met. IEEE 1220 provides success criteria to be used at major technical reviews. For example, some of the success criteria for a preliminary design review are the following:

- Prior completion of subsystem reviews.
- Determine whether total system approach to detailed design satisfies the system baseline.
- Unacceptable risks are mitigated.
- Issues for all subsystems, products, and life-cycle processes are resolved.

The success criteria should be defined in a SEP or other technical plan. The customer should review this plan with the supplier and reach agreement on the success criteria to be used at technical reviews.

Technical Performance Measurement

Technical performance measurements (TPMs) are defined and evaluated to assess how well a system is achieving its performance requirements. TPM uses actual or predicted values from engineering measurements, tests, experiments, or prototypes. IEEE 1220, EIA 632 and "A Guide to the Project Management Body of Knowledge" (PMBOK Guide) [7] provide similar guidance for TPM planning and measurement and for integrating TPM with EVM. For example, EIA 632 states that TPMs predict the future value of key technical parameters of the end-system based on current assessments and that milestones are established for comparing planned and actual progress.

SE Work Products

The SE process generates significant work products that should be included in integrated planning and measured with EV. The process products of IEEE 1220 are as follows:

- Requirements baseline.
- Validated requirements baseline.
- Functional architecture.
- Verified functional architecture.
- Physical architecture.
- Verified physical architecture.

These, or similar, work products should be included in the integrated master schedule, be the output of work packages, and have defined success criteria.

CMM Integration

The CMM Integration℠ (CMMI®) [8] provides many practices that augment the EVMS guidelines. CMMI also lists typical work products (TWPs) within process areas. To ensure traceability of product quality requirements to work tasks and work products, these TWPs, or similar artifacts, should be the outcome of work packages. Here are some TWPs in CMMI.

Requirements development TWPs include the following:

- Derived requirements.
- Product requirements.
- Product-component requirements.
- Interface requirements.
- Activities diagrams and use cases.
- Results of requirements validation.

Technical solution TWPs include the following:

- Documented relationships between requirements and product components.

> *"The distinguishing feature of PBEV is its focus on the customer requirements ... Progress is measured against a plan to fulfill all customer requirements ... management is able to take rapid corrective actions on deviations that threaten customer satisfaction ..."*

- Product-component designs.
- Technical data packages.
- Allocated requirements.
- Verification criteria used to ensure requirements have been achieved.
- Interface control documents.
- Implemented design.

Verification TWPs include these:

- Exit and entry criteria for work products.
- Verification results.

A decision analysis and resolution TWP includes the results of evaluating alternate solutions.

Cost Savings

Measurement costs money. An enterprise must incur significant implementation and sustainment costs to use EVM. These costs can be reduced if the enterprise utilizes an effective process to determine what needs to be measured and limits the measurements to those that meet its information needs and objectives. Furthermore, management can be more effective if it focuses on fewer but more critical measures.

PBEV is cost-effective because it limits the number of activities that should be discretely measured to those that meet defined information needs such as the work products described above. Other measurable activities may be planned as level of effort, if it is not practicable to measure them, or they may be apportioned effort. Additional measurement guidance is available in a Software Engineering Institute technical note [9].

PBEV Characteristics

PBEV is a set of principles and guidelines that specify the most effective measures of cost, schedule, and product quality performance. It has several characteristics that distinguish it from traditional EVMS:

- Plan is driven by product quality requirements, not work requirements.
- Focuses on technical maturity and quality, in addition to work.
- Focuses on progress toward meeting success criteria of technical reviews.
- Adheres to standards and models for SE, software engineering, and project management.
- Provides smart work package planning.
- Enables insightful variance analysis.
- Ensures a lean and cost-effective approach.
- Enables scalable scope and complexity depending on risk.
- Integrates risk management activities with the performance measurement baseline.
- Integrates risk management outcomes with the Estimate at Completion.

PBEV augments EVMS with four additional principles and 16 additional guidelines.

PBEV Principles

The following are PBEV principles that set it apart from EVMS:

1. **Product Scope and Quality.** Integrate product scope and quality requirements into the performance measurement baseline.
2. **Product Quality Requirements.** Specify performance toward satisfying product quality requirements as a base

measure of earned value.
3. **Risk Management Integration.** Integrate risk management with EVM.
4. **Tailor PBEV.** Tailor the application of PBEV according to the risk.

The first two PBEV principals are discussed below in greater detail.

Product Scope and Quality

The first principle introduces two control elements that distinguish PBEV from EVMS: product scope and product quality requirements. This principle focuses on customer satisfaction, which is based on delivery of a product that meets its quality requirements and is within the cost and schedule objectives. The supplier has business objectives to achieve maximum customer satisfaction and to deliver the product with the best possible cost performance.

Product Quality Requirements

In the context of PBEV, the product scope is defined and bounded in terms of product quality requirements. A product quality requirement is a characteristic of a product that is mandatory in order for the product to meet verified customer needs. The set of product quality requirements becomes the product requirements baseline that is integrated into the performance measurement baseline along with work scope, schedule, and cost objectives.

Product quality is also discussed in EIA 632 (Requirement 10):

a. Identify product metrics, and their expected values, that will affect the quality of the product and provide information of the progress toward satisfying the acquirer and other stakeholder requirements, as well as derived requirements.
b. Compare results against requirements to determine degree of technical requirement satisfaction, progress toward maturity of the system (or portion thereof) being engineered, and variations and variances from requirements.

Measuring Quality

Project management processes require progress reporting at periodic intervals, normally monthly. However, progress toward achieving product quality objectives is not always measurable on a periodic basis. For example, a hardware or software component may require the completion and assembly of many enabling work products such as drawings or coded software modules, before the integrated set of work products may be measured against product quality objectives. Consequently, interim progress measurement is normally against the scheduled completion of intermediate, enabling work products.

The completion criterion for an enabling work product, such as a drawing, is determined by the organization's process quality procedures and standards. Successful peer reviews or testing are often used to determine the completeness of interim work products against process quality procedures.

PBEV provides guidance to measure performance toward achieving a combination of the following:

- Schedule objectives for enabling work products that meet process quality objectives.
- Event-driven quality objectives when the event is the achievement of measurable product quality requirements.

Also, the achievement of significant performance requirements may not be measurable at the component or subcomponent level but may depend on achieving planned TPM or other quality objectives that are measurable at higher levels of the system architecture. Consequently, EV at the work package level may be quantitatively linked to the performance of integrated components at a higher level of the work breakdown structure.

During the system definition stage, and with the evolutionary acquisition approach, the real product quality requirements are not yet known [10]. Consequently, activity accomplishment criteria should be established to determine progress assessment until the early product quality requirements have been determined.

Evolutionary Acquisition

Per the DAG, when a program uses an evolutionary strategy, each development increment should have a specific set of parameters with thresholds and objectives appropriate to the increment (DAG, Section 2.3.2). Within the development increment, trade studies are used to resolve conflicts between operational capabilities, and functional and performance requirements (Section 4.5.6).

PBEV supports evolutionary acquisition because it is based on requirements, both those that are known by the end of a development increment and those that are evolving during the increment. The work products specified in PBEV Guideline 2.2 include trade study data to substantiate that system requirements are achievable.

PBEV Guidelines

The PBEV guidelines are listed in Table 2 with references to their source standards and models.

Application at Northrop Grumman

PBEV began with a series of process improvements at Northrop Grumman Integrated Systems. The company was driven by the need to improve software development measurement. Initial improvements were based on Practical Software and Systems Measurement (PSM) [11]. Examples of performance-based measures for EV from PSM include functional requirements status, component status, test status, and increment content-function.

A previous CrossTalk article, "Practical Software Measurement, Performance-Based Earned Value," discusses lessons learned, the improvement process, and provides examples of the types of measures that were discarded and implemented [12], i.e., the measurement of defects was retained as an indicator of quality and a predictor of final cost and schedule. However, various measures of achieved requirements were used for schedule progress and EV instead of defect removal. Also provided is advice regarding the suitability of measuring source lines of code, defect and rework planning, and accounting for deferred functionality. Many of these techniques have been incorporated into the NAVAIR handbook, "Using Software Metrics & Measurement for Earned Value Toolkit" [13].

These improvements paid off during upgrades of the B-2 weapon system. The new measures helped to make it a very successful program.

> The B-2 Spirit Stealth Bomber Program implemented several innovative process improvements using EVM. These include integrating earned value with systems engineering processes, defining improved software engineering metrics to support EVM, and developing a leaner, more effective methodology called Performance-Based Earned Value [PBEV]. The PBEV methodology was used to ensure that the warfighter received the most functionality from software development efforts. On Joint Standoff Weapon/Generic Weapon Interface System, we provided 85 percent more capability than originally planned, on schedule and under budget. [14]

Process improvement at the sector is ongoing. Current policy requires alignment of sector processes with IEEE 1220 and a

Performance-Based Earned Value Guidelines	Source	Section Number
1.1 Establish product quality requirements and allocate these to product components.	CMMI ® PMBOK Guide	RD SP 2.1, 2.2 8.1.1.3
1.2 Maintain bidirectional traceability of product and product component quality requirements among the project plans, work packages, planning packages, and work products.	CMMI PMBOK Guide	RM SP 1.4 5.5
1.3 Identify changes that need to be made to the project plans, work packages, planning packages, and work products resulting from changes to the products quality requirements.	CMMI PMBOK Guide	RM SP 1.5 4.3, 5
2.1 Define the information need and objective to measure progress toward satisfying product quality requirements.	CMMI IEEE 1220 EIA 632 PMBOK Guide	MA SP 1.1 6.8.1.5, 6.8.6 4.2.1, 4.2.2 5.2.3.1, 5.5, 8.1.3.5
2.2 Specify work products and performance-based measures of progress for satisfying product quality requirements as base measures of earned value. Examples are the following: • Results of trade-off analysis. • Allocated requirements developed, implemented into design, or tested successfully. • Achieving planned TPMs. • Meeting entry and success criteria for technical reviews. • Other quality objectives achieved.	CMMI CMMI CMMI IEEE 1220 EIA 632 PMBOK Guide	MA SP 1.2 RD SP 3.3 DAR SP 1.5 6.1.1.13, 6.7.6 6.8.1.5, 6.8.6 4.2.1, 4.2.2, 4.5.1 5.2.3.1, 8.2.1.4, 8.1.3.5, 10.3.1.5, Glossary
2.3 Specify operational definitions for the base measures of earned value, stated in precise, unambiguous terms that address: • Communication: What has been measured, how was it measured, what are the units of measure, and what has been included or excluded? • Repeatability: Can the measurement be repeated given the same definition to get the same results?	CMMI PMBOK Guide	MA SP 1.2 8.1.3.2
2.4 Identify event-based success criteria for technical reviews that include development maturity to date and the product's ability to satisfy product quality requirements.	IEEE 1220 EIA 632	3.1.1.6, 4.12, 5.2.4, 5.3.4, 6.4, 6.6, 6.8.1.5 4.2.2
2.5 Establish time-phased planned values for measures of progress toward meeting product quality requirements, dates of frequency for checking progress, and dates when full conformance will be met.	IEEE 1220 EIA 632 PMBOK Guide	6.8.1.5, 6.8.6, 4.2.1, 4.2.2, Glossary 11.6.2.4
2.6 Allocate budget in discrete work packages to measures of progress toward meeting product quality requirements.	IEEE 1220 EIA 632 PMBOK Guide	6.8.1.5, 6.8.6 4.2.1 5.2.3.1, 10.3.1.5
2.7 Compare the amount of planned budget and the amount of budget earned for achieving progress toward meeting product quality requirements.	IEEE 1220 EIA 632 PMBOK Guide	6.8.1.5, 6.8.6 4.2.2, 6.1.2.6 11.6.2.3
2.8 Use Level of Effort method to plan work that is measurable, but is not a measure of progress toward satisfying product quality requirements, final cost objectives, or final schedule objectives.	CMMI LL	MA SP 1.2
2.9 Perform more effective variance analysis by segregating discrete effort from Level of Effort.	LL	
3.1 Identify changes that need to be made to the project plans, work packages, planning packages, and work products resulting from responses to risks.	PMBOK Guide	11.1.3, 11.6.3.2
3.2 Develop revised estimates of costs at completion based on risk quantification.	PMBOK Guide	7.3.2.3
4.1 Apply PBEV coverage to the whole work breakdown structure or just to the higher risk components.	CMMI LL	MA SP 1.2
4.2 Apply PBEV throughout the whole system development life cycle or initiate after requirements development.	CMMI LL	MA SP 1.2

Key to Abbreviations

RD: Requirements Development Process Area
RM: Requirements Management Process Area
DAR: Decision Analysis and Resolution Process Area
SP: Specific Practice
MA: Measurement and Analysis Process Area
LL: Author's Lessons Learned and Process Improvements

Table 2: *PBEV Guidelines*

process architecture that is CMMI-compliant.

Agile Methods

PMs have begun to use agile development methods to streamline the acquisition process. Alistair Cockburn stated that being agile is a declaration of prioritizing for project maneuverability with respect to shifting requirements, shifting technology, and a shifting understanding of the situation [15]. He also discusses an agile approach to using earned value with burn-down charts where the requirements change frequently [16].

However, using agile acquisition streamlining does not justify the elimination of key program documents and solid program planning. Blaise Durante, the U.S. Air Force deputy assistant secretary for Acquisition Integration, stated that implementing Agile Acquisition requires the following [17]:

- Using innovative thought.
- Flexibility.
- Focusing on outcomes versus non-value-added processes and reviews.
- Empowering program managers to use the system versus being hampered by over-staff management.
- Going back to the basics of program management.

PBEV can support agile systems development. Because it uses requirements-based planning and performance-based measurement, it enables innovation, flexibility, and focusing on outcomes instead of non-value-adding processes. Also, PBEV Guidelines 4.1 and 4.2 support agility by tailoring the application of PBEV. Discrete measurement may be applied only to the higher risk components of the WBS and may be deferred until the initial requirements have been developed.

Conclusions

PBEV supplements traditional EVMS with the best practices of SE, software engineering, and project management standards and models. Its principles and guidelines enable true integration of project cost, schedule, and technical performance.

The distinguishing feature of PBEV is its focus on the customer requirements. Measures of product scope and product quality are incorporated into the project plan. Progress is measured against a plan to fulfill all customer requirements. Measuring the wrong things does not dilute management attention. Consequently, management is able to take rapid corrective actions on deviations that threaten customer satisfaction and business enterprise objectives. PBEV also integrates risk management with EVM. Finally, because it is scalable, risk-based, and responsive to changing customer requirements, PBEV can support evolutionary acquisition and agile systems development.

It is recommended that process improvement programs include plans to incorporate PBEV principles and guidelines.◆

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Note

1. Standards cited include the Standard for Application and Management of the Systems Engineering Process (IEEE 1220), and the Processes for Engineering a System (EIA 632).

About the Author

Paul J. Solomon manages the Earned Value Management Systems (EVMS) for Northrop Grumman Corporation, Integrated Systems. He is an author of the EVMS standard, and received the Department of Defense David Packard Excellence in Acquisition Award. While a Visiting Scientist at the Software Engineering Institute, he authored "Using CMMI to Improve EVM." His book, "Performance-Based Earned Value" will be published by the Institute of Electrical and Electronics Engineers Computer Society. Solomon is a Project Management Professional. He has a Bachelor of Arts and Master of Business Administration from Dartmouth College.

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